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By Roger J. Reed

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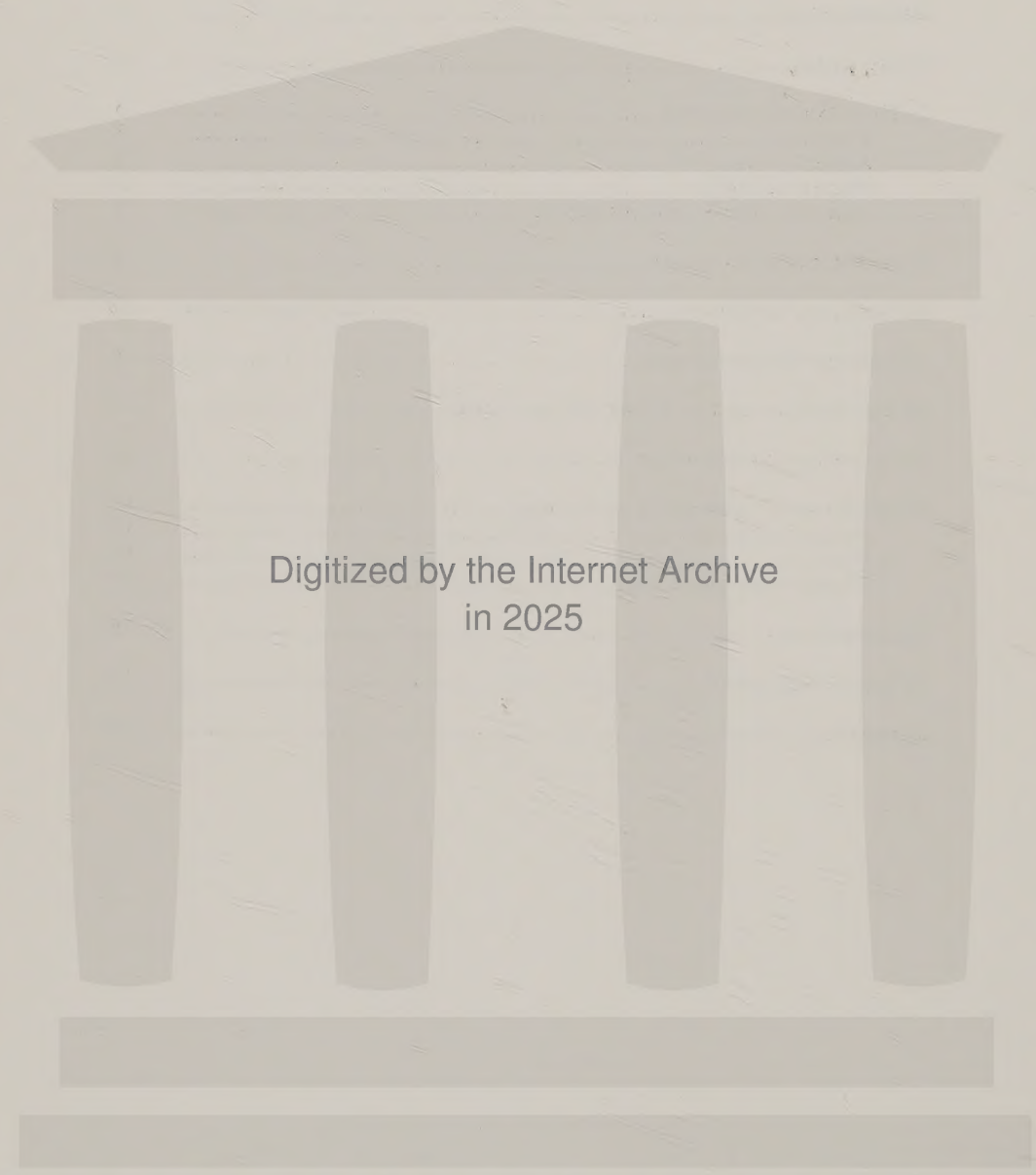

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Some Effects of DDT on the Ecology of Salmon Streams in Southeastern Alaska

By

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ABSTRACT

The effects on stream-dwelling fish and insects of an aerial application of DDT (0.28 kg. (kilogram) per hectare or one-fourth pound per acre) to control black-headed budworm were studied in four streams in southeastern Alaska.

Prespray and postspray sampling was done to determine the food eaten by rainbow and cutthroat trout, the coefficient of condition of trout, the abundance of insects on stones in the stream, the numbers of drifting insects, and the concentrations of DDT in the water, fish, clams, and plankton.

The effects of the DDT were an immediate marked increase in the number of aquatic insects drifting in the stream the day of spraying and the annihilation of aquatic insects within 3 days. No fish were observed to be harmed, although the concentrations of DDT and DDE (biological derivative of DDT) in their bodies increased. The concentrations of DDT also increased in stream waters, plankton, and clams. The one known long-term effect of the DDT on trout was a decline in their condition factor, apparently due to the reduction in their food supply.

The stream insects slowly began to reappear a few weeks after the spraying but did not approach normal numbers until the following summer.

INTRODUCTION

Alaska is one of the last regions in North America where insecticides have not been used on a large scale. Although insecticides have been used at Anchorage, Juneau, Fairbanks, and some military installations in other locations, they probably have affected only limited areas.

Most watersheds in southeastern Alaska have valuable stands of Sitka spruce (Picea sitchensis) and western hemlock (Tsuga heterophylla) which are being cut by an expanding timber industry. Many of these watersheds contain streams with significant populations of trout and salmon.

The U.S. Forest Service and the forest products industry have become concerned about timber losses in southeastern Alaska resulting from infestations of the black-headed budworm (Acleris variana) and the hemlock sawfly (Neodiprion tsugae). The Forest Service has a program to locate areas of potential epidemics of these insects and is considering control methods.

The Forest Service, recognizing the potential hazard of insecticide spraying, proposed in 1960 that a pilot study be undertaken in Alaska to evaluate the effects on fish and wildlife of the application of DDT in forested watersheds. The Bureau of Commercial Fisheries agreed to undertake a 4-yr. (year) study in cooperation with the Bureau of Sport Fisheries and Wildlife and the Alaska Department of Fish and Game.

This paper describes a study by the Bureau of Commercial Fisheries to determine the effects of DDT on insects and fish in two Alaska salmon streams. The general plan was to measure physical and biological features in four streams--two test and two control--before and after spraying with DDT at the rate of 0.28 kg. per hectare (one-fourth pound per acre).

STUDY AREA

Several criteria were used in selecting a suitable study area: (1) The four streams should be located near each other;

[1] The author made this study while employed at the Bureau of Commercial Fisheries Biological Laboratory, Auke Bay, Alaska.

(2) watersheds should have forest cover and terrain representative of southeastern Alaska; (3) streams should contain populations of salmon and resident trout; (4) streams and watersheds should be small (to facilitate environmental studies and to minimize the cost of spraying); and (5) biological and physical characteristics of the streams and watersheds should be similar.

Four watersheds meeting these criteria were found at Skowl Arm, Prince of Wales Island, near Ketchikan (fig. 1). The streams were Cabin (K169,)[2] Old Tom (K163), Saltery Cove (K160), and Virginia (K171) Creeks. Cabin and Virginia Creeks were designated as test streams and Old Tom and Saltery Cove Creeks as control streams. Each pair includes a relatively large and a relatively small stream in terms of physical size and salmon production. The areas of their watersheds range from 7.8 to 28.5 km.^{2} (square kilometers) (3 to 11 square miles).

Each stream is relatively short, has one or more small lakes in its drainage, and is used by at least one species of salmon, sea-run Dolly Varden (Salvelinus malma), rainbow trout (Salmo gairdneri), cutthroat trout (S. clarki), and prickly sculpin (Cottus asper). Diptera (true flies) and Ephemeroptera (mayflies) are the most abundant orders of insects in the streams.

Cabin Creek has the largest watershed, and Orrell and Klinkhart (1963) reported maximum spawning escapements of about 50,000 pink salmon (Oncorhynchus gorbuscha) and 4,000 chum salmon (O. keta). These species use only the lower 365 m. (meters) of the stream for spawning because a series of waterfalls hinders their further migration. Small numbers of sockeye salmon (O. nerka) and coho salmon (O. kisutch) ascend the falls, however, and continue through Cabin Lake where they spawn in the inlet. The lake contains rainbow and cutthroat trout and immature coho and sockeye salmon.

Old Tom Creek has the largest salmon escapement of the four streams. It has had maximum spawning escapements of about 285,000 pink salmon and 54,000 chum salmon (Orrell and Klinkhart, 1963). Pink salmon spawn in the intertidal area, the main stream, and the west fork. Chum salmon use the main stream and east fork. Rainbow trout and immature coho salmon are abundant in the main stream and the east fork.

Saltery Cove Creek is accessible to anadromous fish only to its lower lake, about 0.4 km.

[2] The number in parenthesis is the stream designation used in Orrell and Klinkhart (1963).

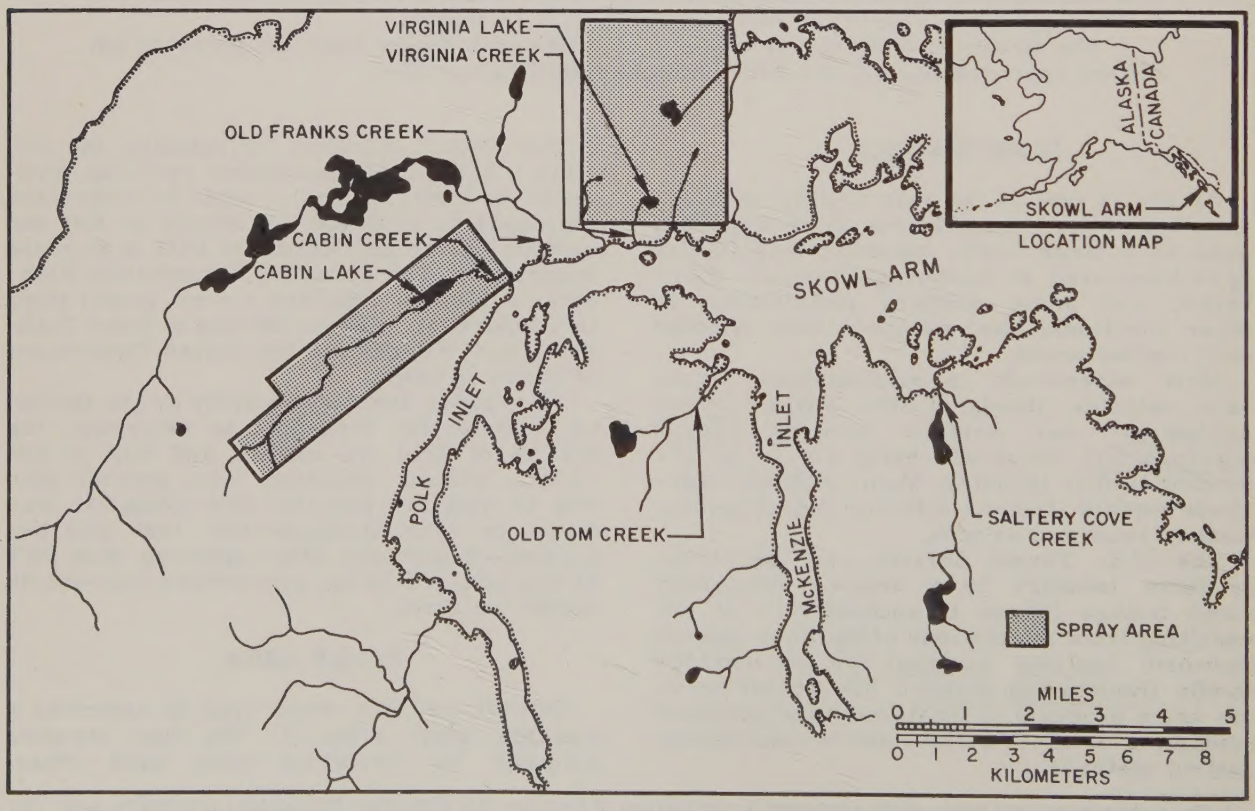

Figure 1.--Skowl Arm, Prince of Wales Island, southeastern Alaska, showing location of study.

(one-fourth mile) above its mouth, and has very limited spawning area. It has small escapements of pink, chum, sockeye, and coho salmon; the lower lake contains cutthroat and rainbow trout.

Virginia Creek is about 1.6 km. (1 mile) long and includes a small boggy lake. The stream has a few rainbow trout, and the lake has resident cutthroat trout. A few pink salmon spawn in the lower end of the stream, and coho salmon spawn near the lake.

Old Franks Creek, located between Virginia and Cabin Creeks, was used as a source of test fish. In addition, samples of water and fish were collected from Old Franks Creek to detect drifting of spray material from the test watersheds.

COLLECTION OF SAMPLES

Fish, aquatic insects, and water samples were collected from the four streams, and clams and plankton were collected near the stream mouths before and after spraying.

Fish

Fish were collected by gill netting in the lakes and by hook-and-line fishing and seining in the streams. They were preserved in 10 percent formalin except those used for DDT analysis, which were frozen. After at least 2 days preservation, weight (to the nearest 0.1 g. (gram)), total and fork lengths (to the nearest millimeter), and sex were determined for each fish. Stomach contents were removed, and the percentage of the total volume contributed by each of 15 categories of food was estimated by the visual method (McCormick, 1940; Raney and Lachner, 1942).

Fish were collected only from the streams between tidewater and the first lake except in the Virginia Creek system where some fish were taken from Virginia Lake because of the scarcity of fish in the creek. Four to six rainbow trout were taken from Old Tom, Cabin, and Saltery Cove Creeks. They ranged between 110 and 160 mm. (millimeters) in total length and between an estimated 20 and 50 g. in weight. Cutthroat trout were taken from Virginia Lake (4 to 6 specimens). They ranged between 125 and 200 mm. in total length and an estimated ~~130~~ 25 and ~~200~~ 55 g. in weight.

Aquatic Insects

The "stone" sample method (Cope, 1961) was used to index the abundance of aquatic insects. This method consists of removing stones about 15.2 cm. (centimeters) in diameter from a riffle and counting the attached insects. In this study, 20 stones were selected from each of two riffle areas in each stream, and Diptera and Ephemeroptera, the most abundant orders, were counted. Sample sites were within 275 m. of the high-tide level. The abundance of insects was determined weekly from June to September, beginning in August 1961. To avoid killing or dislodging the insects, I handled and replaced the stones in the stream with care. Beginning in 1962, numbered plastic tags were wired to each stone so that individual stones could be examined repeatedly. When tagged stones disappeared (probably because of floods or salmon spawning), they were replaced by other stones from the stream.

Drifting aquatic insects were sampled with a Surber square-foot bottom sampler held on the bottom facing into the current for 5 min. (minutes). They were preserved in 37 percent isopropanol.

Water Samples

Selected water properties were determined for each stream weekly throughout the summer seasons. All samples (1 qt. (quart) of water constituted a sample) were taken within 275 m. of the high-tide level. A Hach[3] colorimeter was used to determine pH, turbidity, and oxygen; the methyl-orange method was used to calculate total alkalinity. The waters of all the streams were similar--pH values were close to 7, total alkalinity ranged from about 2 to 45 p.p.m. (parts per million), turbidity ranged from 0 to 60 p.p.m., and oxygen values were generally near saturation. Water temperatures and stream levels were recorded on continuously operating instruments.

Series of samples were taken from the surface water on the days of spraying and before and after spraying to test for the presence of DDT. The samples were placed in vacuum bottles or glass mason jars to which a few drops of dilute sulfuric acid were added to prevent breakdown of the DDT. On the "spray days," water was collected at 2-hr. (hour) intervals. In addition to the surface samples, intragravel water was collected from Old Tom and Cabin Creeks before and during the day of spraying. Rigid plastic pipes about 2.5 cm. in diameter were driven about 25.4 cm. into the gravel, and samples were withdrawn from the bottom of the pipes with a long syringe.

Marine Clams and Plankton

Several common species of marine clams were dug from beaches in the vicinity of each study stream in 1963 both before and after spraying. Seven to eight clams were dug at each site. The samples (150 g. of material) were frozen and later tested for DDT.

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[3] Trade name referred to in this publication does not imply endorsement of commercial product.

Plankton was obtained from the ocean in the vicinity of each study area before and after the spraying. A plankton net about 45.7 cm. in diameter (No. 20 mesh) was towed behind a boat at a depth of about 1.2 m. The samples were put in quart jars--about one-half quart of plankton and the rest sea water. They were frozen and later analyzed for DDT.

INSECTICIDE APPLICATION

DDT was applied to the test watersheds, Virginia and Cabin Creeks, at 0.28 kg. per hectare. Fuel oil was used as a vehicle, and the mixture was sprayed from an airplane. No attempt was made to avoid spraying the streams.

The plan was to spray both watersheds the same day. Spraying began on Virginia Creek on June 18, 1963, but was halted when high winds arose, after only one-third of the watershed had been covered. The rest of the Virginia Creek watershed and all of the Cabin Creek watershed were sprayed under ideal conditions on June 21, 1963. Technical details of the application, not pertinent to this report, are described in a report by the Forest Service.[4]

INSECTICIDE ANALYSES

Samples of water, fish, clams, and plankton were sent to the Wisconsin Alumni Research Foundation for analyses of DDT and its biological derivative DDE. The early analyses were by paper chromatography and the later ones by electron-capture gas chromatography. The concentrations of insecticides were expressed in parts per million. The lower limits of reliable sensitivity of analytical procedure were 0.005 p.p.m. for DDT in the water samples and 0.002 p.p.m. for DDT and DDE in fish (whole), clams (excluding shells), and plankton.

PRESPRAY OBSERVATIONS

Prespray observations in the study areas from August 1961 to mid-June 1963 established normal levels and seasonal variation of abundance of aquatic insects, diet of trout, and concentrations of DDT in water, fish, clams, and plankton. The numbers of insects drifting downstream were sampled a few days before spraying and on the day of spraying.

[4] U.S. Forest Serv. Skowl Arm DDT pilot project, 46 p. On file Forest Serv., Reg. 10, Juneau, Alaska.

The average abundance of Diptera and Ephemeroptera on test stones at weekly intervals during the summers are shown in figures 2 to 5. In all four streams abundance normally increased from low levels in early June to a high in late July and early August and then declined gradually to early September (except in Saltery Cove Creek in 1963). Samples of the larvae of aquatic insects from test stones were identified to genus. The four most abundant orders and the genera of each were: (1) Plecoptera: Arcynopteryx, Hastaperla, Claassenia, and Acroneuria; (2) Ephemeroptera: Cinygmula, Iron, Anepeorus, Ameletus, Paraleptophlebia, Ephemerella, Baetis, and Apobaetis; (3) Trichoptera: Glossosoma, Chimarra, and Ochrotrichia; (4) Diptera: Tipula, Dixa, Simulium, and Dolichopus.

Drifting aquatic insects were sampled for three 5-min. periods in each of the four streams on June 16, 1963, a few days before spraying. Only Diptera were caught in the nets--10 in Virginia Creek, 7 in Old Tom Creek, 4 in Cabin Creek, and none in Saltery Cove Creek.

Rainbow trout were collected in Old Tom, Cabin, and Saltery Cove Creeks and cutthroat trout in Virginia Lake in July 1962 to study the normal diet. The contents of the stomachs of fish collected from the four systems are presented graphically by major groupings in figures 6 and 7 and in more detail in tables 1 and 2. For comparative purposes, the figures and tables give both prespray (1962) and postspray (1963 and 1964) data. The normal diet contained about 25 to 50 percent aquatic insects by volume. The "debris" category was composed principally of sand and bits of leaves and twigs.

I could find no record of any earlier large-scale use of chemical insecticides on Prince of Wales Island; therefore, I did not expect to find DDT in water samples collected before the test spraying of this program. Yet the samples of water collected in 1961 from the Cabin Creek watershed contained an unusually high level of DDT for an unsprayed area (table 3). I made a thorough but unsuccessful search for clues as to the source of the contamination. The validity of the DDT determinations made in 1961 was supported by the analyses of fish collected in 1962--fish sampled from Cabin Creek and Virginia Lake contained concentrations of DDT and DDE greater than usual for an unsprayed area, though normal levels existed in Old Tom and Saltery Cove Creeks (table 3). The concentrations of DDT and DDE in water, fish, clams, and plankton were normal in all the study areas in June 1963 before spraying.

The prespray data thus established the normal summer abundance of aquatic Diptera and Ephemeroptera in the streams, the diet of the fish, and the prespray levels of DDT in water, clams, plankton, and fish.

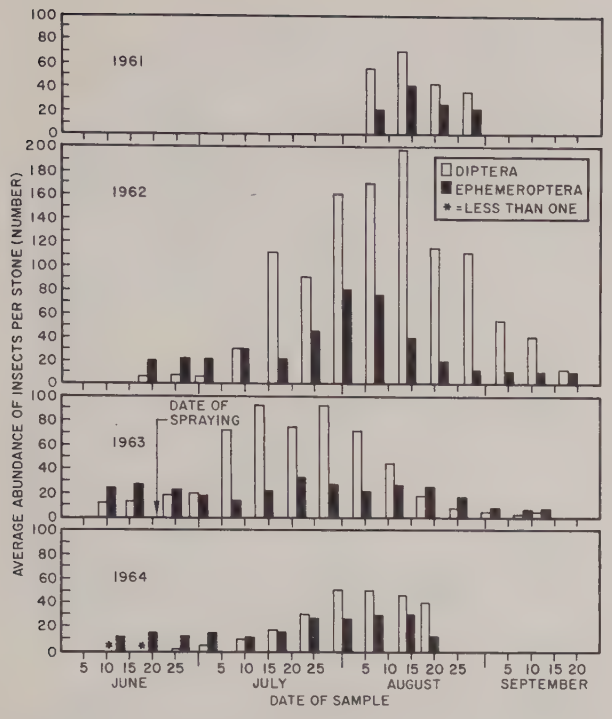

Figure 2.--Average number of Diptera and Ephemeroptera per test stone from weekly samples of 40 stones, 1961-64, Old Tom Creek (control stream).

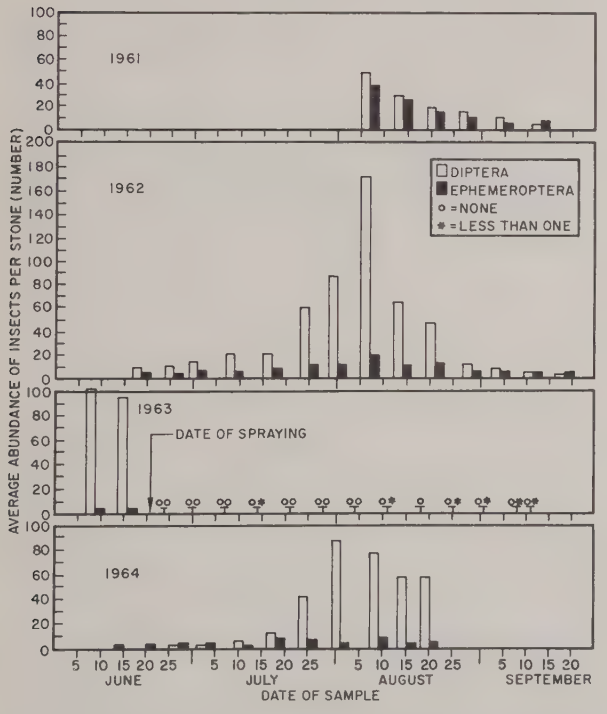

Figure 3.--Average number of Diptera and Ephemeroptera per test stone from weekly samples of 40 stones, 1961-64, Cabin Creek (test stream).

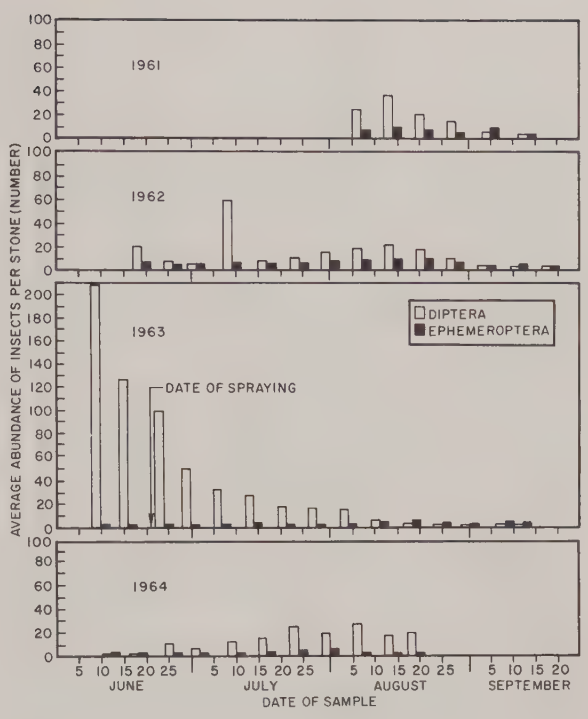

Figure 4.--Average number of Diptera and Ephemeroptera per test stone from weekly samples of 40 stones, 1961-64, Saltery Cove Creek (control stream).

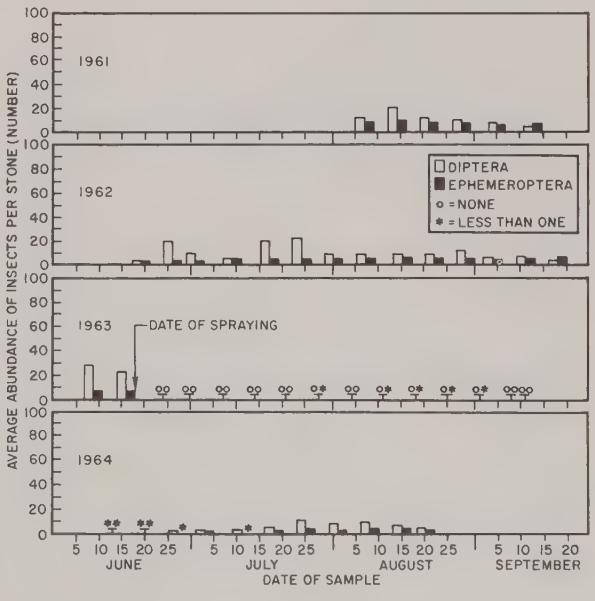

Figure 5.--Average number of Diptera and Ephemeroptera per test stone from weekly samples of 40 stones, 1961-64, Virginia Creek (test stream).

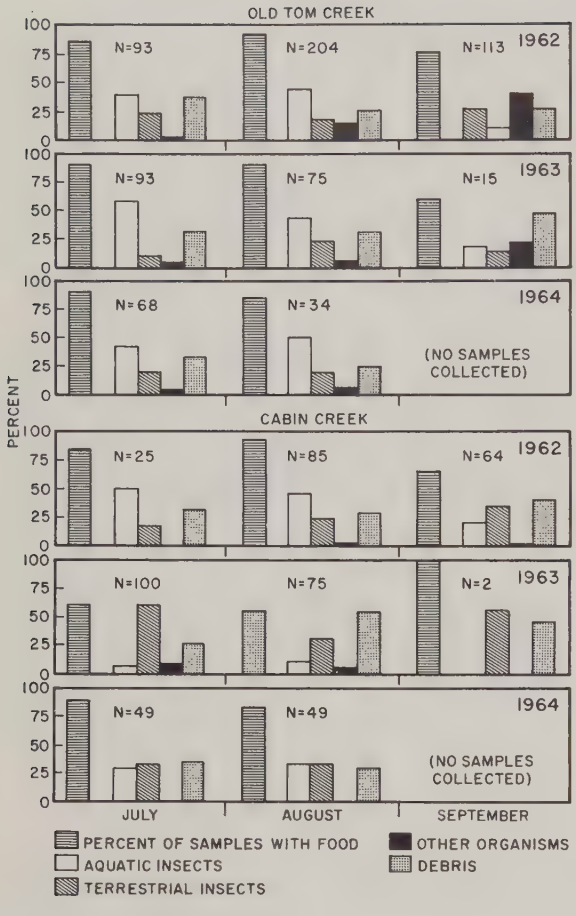

Figure 6.--Stomach contents of rainbow trout from Old Tom and Cabin Creeks, showing percentage of sample with food and percentage total volume of four food categories before spraying (1962) and after (1963-64).

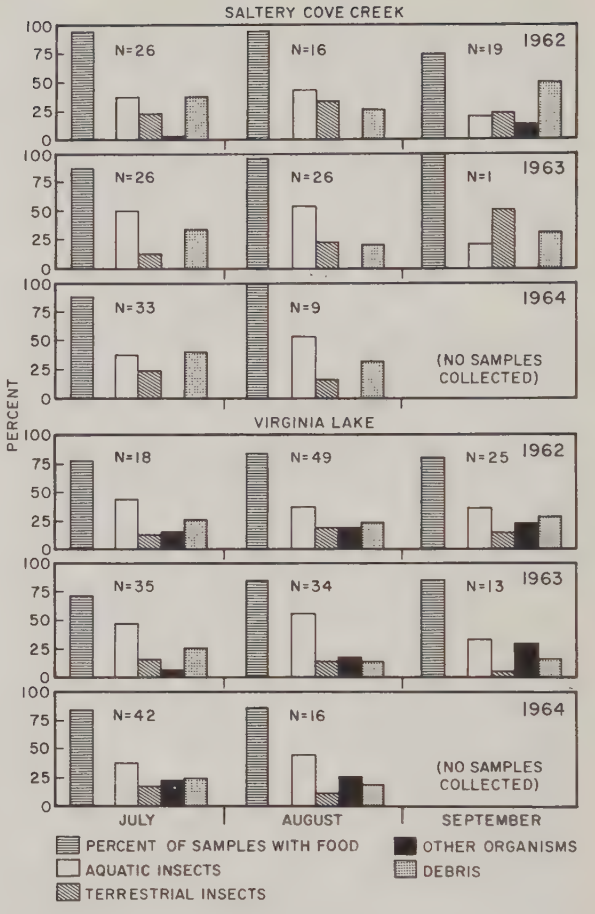

Figure 7.--Stomach contents of rainbow trout from Saltery Cove Creek and cutthroat trout from Virginia Lake, showing percentage of sample with food and percentage total volume of four food categories before spraying (1962) and after (1963-64).

Table 1.--Percentage frequency of occurrence and (in parentheses) percentage total volume of food in stomachs of rainbow trout from Cabin Creek and cutthroat trout from Virginia Lake (test waters) before spraying (1962) and after (1963-64)

[Tr, trace]

Locality and date	Stomachs examined	Stomachs with food	Insects								Other organisms						Debris
			Aquatic					Terrestrial									
			Diptera	Ephemeroptera	Trichoptera	Plecoptera	Odonata	Coleoptera	Hymenoptera	Lepidoptera	Isopoda	Hydracarina	Diplopoda	Gastropoda	Fish	Fish eggs	
	Number	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Cabin Creek:																	
July 1962....	25	84	85 (46)	28 (4)	0	0	0	28 (16)	4 (2)	0	0	0	0	0	0	0	100 (32)
July 1963....	100	59	Tr (1)	1 (1)	0	0	Tr (4)	35 (54)	1 (6)	0	0	0	1 (6)	Tr (2)	0	0	100 (27)
July 1964....	49	90	41 (28)	20 (2)	0	0	0	27 (30)	Tr (3)	0	0	0	Tr (1)	0	0	0	100 (36)
Aug. 1962....	85	94	85 (40)	30 (5)	Tr (1)	0	0	20 (9)	0	31 (15)	0	Tr (1)	0	0	Tr (Tr)	0	100 (29)
Aug. 1963....	75	55	Tr (1)	0	0	Tr (6)	Tr (3)	32 (20)	Tr (4)	1 (7)	0	0	Tr (4)	Tr (1)	0	0	90 (54)
Aug. 1964....	49	84	49 (29)	27 (4)	0	0	0	24 (25)	Tr (2)	7 (6)	0	0	Tr (2)	Tr (2)	0	0	100 (30)
Sept. 1962...	64	66	33 (18)	16 (3)	Tr (Tr)	0	0	40 (25)	0	19 (11)	0	Tr (1)	0	0	0	0	100 (41)
Sept. 1963...	2	100	0	0	0	0	0	100 (55)	0	0	0	0	0	0	0	0	100 (45)
Virginia Lake:																	
July 1962....	18	78	35 (11)	0	0	0	42 (33)	28 (14)	0	0	0	0	0	7 (2)	7 (13)	0	100 (27)
July 1963....	35	72	Tr (2)	0	0	0	52 (46)	28 (16)	0	0	0	0	0	2 (6)	0	0	90 (26)
July 1964....	42	86	22 (6)	0	0	0	48 (32)	39 (16)	0	0	0	0	0	36 (18)	7 (4)	0	100 (23)
Aug. 1962....	49	84	31 (11)	0	0	0	34 (26)	41 (19)	0	Tr (Tr)	0	0	0	19 (12)	12 (7)	0	100 (24)
Aug. 1963....	34	85	0	0	Tr (2)	0	69 (54)	35 (14)	0	0	0	0	0	24 (15)	Tr (3)	0	86 (13)
Aug. 1964....	16	87	29 (8)	0	0	0	57 (38)	43 (10)	0	0	0	0	0	36 (20)	14 (6)	0	100 (18)
Sept. 1962...	25	80	9 (4)	0	0	0	42 (32)	19 (15)	0	0	0	0	0	19 (16)	9 (7)	0	100 (29)
Sept. 1963...	13	85	0	0	0	0	45 (33)	10 (6)	0	0	0	0	10 (7)	36 (23)	0	0	100 (32)

Table 2.--Percentage frequency of occurrence and (in parentheses) percentage total volume of food in stomachs of rainbow trout from Old Tom and Saltery Cove Creeks (control streams) before spraying (1962) and after (1963-64)

[Tr, trace]

Locality and date	Stomachs examined	Stomachs with food	Insects								Other organisms						Debris
			Aquatic					Terrestrial									
			Diptera	Ephemeroptera	Trichoptera	Plecoptera	Odonata	Coleoptera	Hymenoptera	Lepidoptera	Isopoda	Hydracarina	Diplopoda	Gastropoda	Fish	Fish eggs	
	Number	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Old Tom Creek:																	
July 1962....	93	86	77 (32)	26 (4)	6 (3)	0	0	30 (20)	Tr (3)	0	0	Tr (1)	0	0	0	0	100 (37)
July 1963....	100	89	55 (39)	44 (12)	18 (7)	0	0	21 (8)	Tr (1)	0	Tr (1)	0	Tr (4)	0	Tr (Tr)	0	100 (32)
July 1964....	68	88	71 (31)	31 (7)	13 (4)	0	0	40 (19)	Tr (2)	0	Tr (1)	0	Tr (3)	0	0	0	100 (33)
Aug. 1962....	204	93	77 (37)	18 (4)	2 (3)	0	0	27 (13)	Tr (Tr)	3 (4)	Tr (2)	0	0	0	Tr (Tr)	19 (12)	97 (25)
Aug. 1963....	75	91	53 (22)	37 (15)	13 (6)	0	0	37 (19)	Tr (1)	Tr (3)	0	0	Tr (4)	Tr (Tr)	0	0	99 (30)
Aug. 1964....	34	85	66 (42)	28 (5)	10 (4)	0	0	21 (15)	Tr (2)	Tr (2)	0	0	0	0	0	7 (6)	100 (25)
Sept. 1962...	113	76	45 (19)	7 (1)	7 (5)	0	0	10 (5)	0	Tr (4)	0	0	0	0	0	49 (39)	98 (27)
Sept. 1963...	15	60	0	44 (19)	0	0	0	33 (13)	0	0	0	0	33 (21)	0	0	0	100 (47)
Saltery Cove Creek:																	
July 1962....	26	93	92 (36)	0	12 (1)	0	0	29 (14)	0	16 (7)	0	Tr (3)	0	0	0	0	100 (38)
July 1963....	25	88	95 (38)	3 (6)	1 (5)	Tr (2)	0	2 (13)	0	0	0	0	0	0	Tr (2)	0	100 (35)
July 1964....	33	88	78 (28)	7 (5)	14 (4)	0	0	24 (20)	Tr (3)	0	0	0	0	0	0	0	100 (40)
Aug. 1962....	16	94	80 (36)	13 (2)	6 (4)	0	0	40 (11)	0	46 (22)	0	0	0	0	0	0	100 (25)
Aug. 1963....	26	96	75 (40)	13 (6)	13 (8)	0	0	38 (18)	0	Tr (4)	0	0	0	0	0	0	92 (25)
Aug. 1964....	9	100	100 (39)	22 (8)	34 (6)	0	0	34 (12)	0	22 (4)	0	0	0	0	0	0	100 (32)
Sept. 1962...	19	74	64 (16)	0	22 (3)	0	0	22 (13)	0	14 (9)	0	0	0	0	0	14 (12)	100 (48)
Sept. 1963...	1	100	100 (20)	0	0	0	0	100 (50)	0	0	0	0	0	0	0	0	100 (30)

Table 3.--Concentrations of DDT and DDE in materials collected from four streams, Prince of Wales Island, Alaska, before spraying

[Each figure represents one sample. N.D., not detectable]

Date of collection and material	Cabin Creek		Virginia Lake		Old Tom Creek		Saltery Cove Creek	
	DDT	DDE	DDT	DDE	DDT	DDE	DDT	DDE
	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.
September 1961:								
Water (stream).....	0.01	--	--	--	--	--	--	--
Water (lake).....	.01	--	--	--	--	--	--	--
August 1962:								
Water.....	Trace	--	Trace	--	Trace	--	Trace	--
Fish.....	.16	0.66	0.10	0.52	0.03	0.08	0.04	0.07
June 1963:								
Water.....	Trace	--	Trace	--	Trace	--	Trace	--
Fish.....	.05	.06	do	Trace	do	Trace	.03	.04
Clams.....	Trace	.03	do	do	do	do	Trace	Trace
Plankton.....	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

OBSERVATIONS ON THE DATES OF SPRAYING

Observations were made in the test and control streams during the day of spraying to measure the immediate results. Samples of water (for DDT analysis) and drifting insects were collected at 2-hr. intervals starting 1 hr. after spraying began. In early June, rainbow trout were collected in Old Tom and Old Franks Creeks. Some of these fish were preserved for DDT determination,[5] and others were placed in cages in each of the four study streams. Some of the trout from the cages and clams or plankton from the vicinity of the two creeks were collected at the end of the day of spraying for DDT analysis.

Spraying of the insecticide began with the Virginia Creek watershed on June 18, 1963, but was discontinued after about one-third of the area had been treated. Strong winds arose suddenly and carried some spray out of the target area.

The first observations on the day of spraying were of the immediate results of the incomplete spraying of the Virginia Creek area. Collections were made in both Virginia Creek and its control stream, Saltery Cove Creek. Because the odor of the spray mixture was detected downwind from the Virginia Creek watershed at Cabin and Old Franks Creeks, the waters of these two streams were also sampled.

Apparently, little or no spray reached these streams on June 18. Neither the number of drifting insects (tables 4 and 5) nor the DDT in the water (table 6) increased. Only normal levels (trace) of DDT were found in the fish held in cages in Virginia and Saltery Cove Creeks and in clams taken near the creeks.

The rest of the Virginia Creek watershed and all of the Cabin Creek watershed were sprayed on June 21 under ideal conditions.

After the spraying on June 21, the first catches of drifting insects (1 hr. after spraying) indicated that DDT had entered the test streams; drifting Diptera and Ephemeroptera (mostly dead or dying) were many times more abundant in the test than in the control streams. The greatest numbers of insects were caught 3 hr. after spraying; later samples contained progressively fewer. Only a few drifting insects (all alive and apparently normal) were captured in the control streams (Old Tom and Saltery Cove Creeks). A similar marked increase in the number of drifting insects in streams soon after spraying has been recorded by other investigators: Bridges and Andrews (1961) and Cope (1961) in Montana; Frey (1961) in Georgia; and Hoffman and Surber (1948) in West Virginia. In these earlier experiments, however, DDT was applied at a rate of 1.12 kg. per hectare, in contrast to 0.28 kg. per hectare in southeastern Alaska.

No evidence appeared of distress or mortality of the fish in the cages at the mouth of each of the four streams or free in the streams.

The presence of significant quantities of DDT in the sprayed streams that was indicated by the increased number of drifting insects was verified by the analysis of the water collected on June 21 (table 6). The DDT-contaminated water was flushed out of Cabin Creek within 10 hr., but a concentration of 0.5 p.p.m. was still present in Virginia Creek after 12 hr. Water samples from the inlet to Cabin Lake shortly after spraying showed only trace amounts of DDT; little spray reached the stream above the lake.

[5] The fish tested contained only trace amounts of DDT and DDE.

Table 4.--Drifting insects caught in 5-min. sets with Surber sampler on test streams after spray was applied on June 18 and 21, 1963, Prince of Wales Island, Alaska

Creek and date	Time after spraying	Aquatic insects					Terrestrial insects					
		Diptera	Ephemeroptera	Trichoptera	Plecoptera	Others	Diptera	Coleoptera	Hymenoptera	Hemiptera	Others	Total
	Hours	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number
Cabin Creek:												
June 21.....	1	38	19	0	1	2	0	0	0	1	0	61
Do.....	3	64	158	13	29	0	4	8	0	0	0	276
Do.....	5	10	70	7	12	2	2	2	0	0	0	105
Do.....	7	8	56	2	6	0	1	1	0	2	1	77
Do.....	9	6	32	4	5	1	1	1	0	0	1	51
Do.....	11	3	22	0	2	0	1	0	0	0	0	28
Virginia Creek:												
June 18.....	1	6	0	0	2	0	2	0	0	0	0	10
Do.....	3	9	0	0	0	0	0	0	0	0	0	9
Do.....	5	5	0	0	0	0	0	0	0	0	0	5
Do.....	7	3	0	0	0	0	3	0	0	0	0	6
June 21.....	1	7	67	2	8	1	7	0	3	0	2	97
Do.....	3	11	136	1	17	2	9	3	0	0	4	183
Do.....	5	13	28	2	6	1	14	0	1	0	0	65
Do.....	7	10	7	0	0	0	18	0	0	0	1	36
Do.....	9	3	2	0	3	0	8	1	1	0	4	22
Do.....	11	4	0	0	1	0	12	0	0	0	3	20

Table 5.--Drifting insects caught in 5-min. sets with Surber sampler on two control streams after spray was applied to nearby test streams on June 18 and 21, 1963, Prince of Wales Island, Alaska

Creek and date	Time after spraying	Aquatic insects					Terrestrial insects					
		Diptera	Ephemeroptera	Trichoptera	Plecoptera	Others	Diptera	Coleoptera	Hymenoptera	Hemiptera	Others	Total
	Hours	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number
Old Tom Creek:												
June 21.....	1	2	0	0	0	0	0	0	0	0	0	2
Do.....	3	1	0	0	0	1	0	0	0	0	0	2
Do.....	5	4	0	0	0	0	0	0	0	0	0	4
Do.....	7	3	0	0	0	0	0	0	0	0	0	3
Do.....	9	1	0	0	0	0	0	0	0	0	0	1
Do.....	11	0	0	0	0	1	0	0	0	0	0	1
Saltery Cove Creek:												
June 18.....	1	0	0	0	0	0	0	0	0	0	0	0
Do.....	3	2	0	0	0	0	0	0	0	0	0	2
Do.....	5	0	0	0	0	0	0	0	0	0	0	0
Do.....	7	0	0	0	0	0	0	0	0	0	0	0
June 21.....	1	1	0	0	0	0	0	0	0	0	0	1
Do.....	3	2	0	0	0	0	0	0	0	0	0	2
Do.....	5	0	0	0	0	0	0	0	0	0	0	0
Do.....	7	2	0	0	0	0	0	0	0	0	0	2
Do.....	9	0	0	0	0	0	0	0	0	0	0	0
Do.....	11	0	0	0	0	0	0	0	0	0	0	0

Table 6.--Concentrations of DDT and DDE in materials collected from test and control streams on June 18 and 21, 1963, after spraying, Prince of Wales Island, Alaska

[Trace, <0.005 p.p.m. in water, <0.02 p.p.m. in fish and clams]

Date of collection and material	Time after spraying	Test streams				Control streams[1]			
		Cabin Creek		Virginia Creek		Old Tom Creek		Saltery Cove Creek	
		DDT	DDE	DDT	DDE	DDT	DDE	DDT	DDE
	Hours	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.
June 18									
Water	1	Trace	--	Trace	--	--	--	Trace	--
Do	3	--	--	do	--	--	--	do	--
Do	5	--	--	do	--	--	--	do	--
Do	7	--	--	do	--	--	--	do	--
Do	9	--	--	do	--	--	--	do	--
Fish	-	--	--	do	Trace	--	--	do	Trace
Clams	-	--	--	do	do	--	--	do	do
June 21									
Water	1	1.6	--	1.2	--	Trace	--	do	--
Do	3	1.2	--	1.9	--	do	--	do	--
Do	5	.8	--	.5	--	do	--	do	--
Do	7	1.2	--	Trace	--	do	--	do	--
Do	9	Trace	--	.6	--	do	--	do	--
Do	11	do	--	.5	--	do	--	do	--
Fish	-	do	Trace	Trace	Trace	do	Trace	do	Trace
Plankton	-	do	do	do	0.02	do	do	do	do

[1] The water in Old Franks Creek contained a trace of DDT on June 18, 1 hr. after spraying began. No other samples were taken.

All intragravel water sampled in Cabin Creek (test stream) and Old Tom Creek (control) contained only traces of DDT. In other studies, flushing of DDT from sprayed drainages has been found to be highly irregular. Concentrations of DDT toxic to fish (greater than 0.05 p.p.m.--Alderdice and Worthington, 1959) were still present in a British Columbia stream 12 days after an application of DDT at the rate of 1.12 kg. per hectare (Crouter and Vernon, 1959). In Montana, Graham and Scott[6] found that most of the DDT applied to the watershed at 1.12 kg. per hectare soon disappeared from the stream water; 32 hr. after spraying the concentration was less than 0.01 p.p.m. Cope and Park,[7] at the same application rate, found no DDT in the stream 27 hr. after the spraying.

[6] Graham, Richard J., and David O. Scott. 1959. Effects of an aerial application of DDT on fish and aquatic insects in Montana. Mont. State Fish Game Dep., U.S. Fish Wildl. Serv., and U.S. Forest Serv., Final Rep. 1957 and 1958, 35 p.

[7] Cope, Oliver B., and Barry C. Park. 1957. Effects of forest insect spraying on trout and aquatic insects in some Montana streams. U.S. Fish Wildl. Serv., U.S. Forest Serv., and Mont. State Fish Game Dep., Progr. Rep. 1956, 56 p.

POSTSPRAY OBSERVATIONS

The first postspray rainfall (about 0.8 cm.) occurred over Skowl Arm on the morning of June 23, 1963. To determine if DDT was leaching or washing into the streams from the treated watersheds, four samples of water were collected from each stream at 2-hr. intervals after the rain began. Trout were collected from the cages at the mouth of each stream that afternoon. Only trace amounts of DDT were found in the water samples and in the fish samples, except for fish from Virginia Creek (table 7). In the trout from Virginia Creek the concentrations of DDT and DDE had increased from "trace" (<0.02 p.p.m.) to 0.02 and 0.03 p.p.m., respectively. Neither Cope and Park (see footnote 7) nor Graham and Scott (see footnote 6) found increased levels of DDT in streams after the first heavy postspray rainfall.

The first postspray assessment of aquatic insects was made on June 24. No insects were found on the tagged stones in the test streams, Cabin and Virginia Creeks (figs. 3 and 5). Additional stones were examined carefully in each sprayed stream from the mouth to the lake; although a few water mites (Hydracarina) were observed occasionally,

Table 7.--Concentrations of DDT and DDE in materials collected from test and control streams beginning after first postspray rainfall on June 23, 1963, Prince of Wales Island, Alaska

[Trace, < 0.005 p.p.m. in water, < 0.02 p.p.m. in fish and clams]

Date of collection and material	Test streams				Control streams[1]			
	Cabin Creek		Virginia Creek		Old Tom Creek		Saltery Cove Creek	
	DDT	DDE	DDT	DDE	DDT	DDE	DDT	DDE
	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.
June 23:								
Water.....	Trace	--	Trace	--	Trace	--	Trace	--
Fish.....	do	Trace	0.02	0.03	do	Trace	do	Trace
July 23:								
Water.....	Trace	--	Trace	--	do	--	do	--
Fish.....	2.3	0.90	3.0	1.5	do	Trace	do	Trace
Clams.....	Trace	Trace	Trace	Trace	do	do	do	do
August 24:								
Water.....	Trace	--	Trace	--	do	--	do	--
Fish.....	4.2	2.7	[2] 2.9	1.3	do	Trace	do	Trace
Clams.....	Trace	Trace	Trace	Trace	do	do	do	do
Sept. 10-11:								
Water.....	Trace	--	Trace	--	do	--	do	--
Fish.....	2.5	1.8	[2] 6.2	3.3	do	Trace	do	Trace
Clams.....	Trace	Trace	Trace	Trace	do	do	do	do

[1] Fish from Old Franks Creek (unsprayed) contained 0.75 p.p.m. DDT on July 23 and 0.55 p.p.m. on August 24, and 0.30 p.p.m. DDE on both dates. No other samples were taken on these dates.
[2] Fish collected from Virginia Lake.

no aquatic insects could be found. In the control streams, the numbers of aquatic insects had not changed from the normal prespray summer abundance (figs. 2 and 4). Kerswill and Elson (1955) reported little or no reduction in numbers of water mites after DDT had been sprayed at 0.56 kg. per hectare, but the only living insect larvae they found were in a pool in a small tributary.

Reductions in numbers of aquatic insects have been observed in other studies of the effects of DDT application on the watershed, but complete eradication has never been reported. Among investigators who reported drastic reductions of aquatic insects after DDT had been sprayed at the rate of 0.22 to 1.12 kg. per hectare were: Warner and Fenderson;[8] Crouter and Vernon (1959); Graham and Scott;[9] Ide (1957); Webb and Macdonald (1958); Hoffman and Surber (1949); Hoffman and Drooz (1953); and Kerswill and Elson (1955). Todd and Jackson (1961) found no significant mortality of aquatic insects or of salmonids after a watershed had been sprayed with DDT at the rate of 0.28 kg. per hectare, but in their studies a strip 0.8 km. (0.5 mile) wide was left unsprayed on each side of the stream.

Stomachs of rainbow and cutthroat trout were collected periodically from July 1962 through August 1964. The contents of stomachs of trout from one of the test streams, Cabin Creek, in 1963 (after spraying) were markedly different from those in 1962 and 1964 (fig. 6). The number of empty stomachs and the percentage of terrestrial insects and debris were much greater in 1963 than in 1962 or 1964. The feeding habits of cutthroat trout from Virginia Lake in the other test watershed (fig. 7) and rainbow trout from the control streams, Old Tom Creek (fig. 6) and Saltery Cove Creek (fig. 7), did not change from 1962 to 1964.

Changes in the diet of fish in a stream due to changes in the abundance of aquatic insects resulting from DDT applications have not been well documented because of lack of adequate prespray samples and control areas. Food studies in conjunction with spraying of DDT are discussed in several papers, among which are Cope and Park (see footnote 7); Graham and Scott (see footnote 9); and

[8] Warner, Kendall, and Owen C. Fenderson. 1959. Effects of forest insect spraying on northern Maine trout streams. Maine Dep. Inland Fish. Game. Dingell Johnson Proj. F-8-R-7, 32 p.

[9] Graham, Richard J., and David O. Scott. 1958. Effects of forest insect spraying on trout and aquatic insects in some Montana streams. U.S. Fish and Wildl. Serv., Mont. State Fish Game Dep., and U.S. Forest Serv., Final Rep. 1956 and 1957, 50 p.

Warner and Fenderson (see footnote 8).

Postspray samples of fish, clams, and water were taken from the four study areas in 1963. The concentration of DDT and DDE increased progressively in fish from Virginia Creek and Virginia Lake; in Cabin Creek the values increased from June through August and declined in September (table 7). Fish from Old Tom and Saltery Cove Creeks had only traces of DDT and DDE, and traces were found also in clams and in the surface and intragravel water in all four systems.

Late in August 1963, eggs taken from several pink and chum salmon in Old Tom Creek were fertilized and buried in the gravel in Old Tom and Cabin Creeks for 19 days to test the possibility that living eggs might accumulate DDT from the intragravel water. Subsequent analysis showed only traces of DDT and DDE.

The final postspray observations in the four streams were made from June to late August 1964. Emphasis of the 1964 studies was on measuring the repopulation of aquatic insects on test stones in the sprayed streams (Cabin and Virginia Creeks), the effects of annihilation of aquatic insects in 1963 on the condition of trout, and the concentrations of DDT and DDE in fish in both streams.

The seasonal changes of abundance of aquatic insects in the four streams in 1964 were similar to those in all the streams in 1961 and 1962 (figs. 2 to 5). In 1963, the seasonal changes of abundance in the unsprayed streams were unaccountably somewhat different from other years (figs. 2 and 4), but the significant point is that the unsprayed streams continued to support flourishing insect populations and were unaffected by nearby spraying. In 1964, not only had the normal seasonal changes in abundance been reestablished in the test streams, but by August the numbers had approached prespray levels (figs. 3 and 5).

The DDT and DDE content of rainbow trout from the control streams, Old Tom and Saltery Cove Creeks, remained at the low prespray levels. Both DDT and DDE in cutthroat trout from Virginia Lake and rainbow trout from Cabin Creek had decreased markedly from the 1963 postspray concentrations (table 8). Because the water samples of June 1964 (table 8) had only trace amounts of DDT, water analyses were discontinued.

The diet of trout in the control watersheds (Old Tom and Saltery Cove Creeks) was about the same in 1964 as in previous years (tables 1 and 2 and figs. 6 and 7), and that of trout in the test watersheds (Cabin and Virginia Creeks) had returned to the prespray conditions of 1962.

To determine if the drastic change in diet that resulted from annihilation of the aquatic insects affected the condition of the trout, condition factors (K) were calculated from the formula

$$K = \frac{\text{Weight (grams)} \times 10^5}{\text{Fork length (millimeters)}^3}$$

Mean values of K were determined for fish collected each year from each study area in July and August (table 9). The length-frequency distribution of the fish used in the calculations of condition was similar every year. The condition of fish generally declined in the two test areas but remained nearly constant in the control streams. Although Diptera and Ephemeroptera were present in the test streams in normal prespray numbers by August 1964 (as evidenced by counts of insects on stones and in stomach samples), condition did not improve. The condition factors of trout from Cabin Creek and Virginia Lake reached the lowest values of the 3 yr. in 1964. Fish in the test streams may not have had time to recover from the poor condition resulting from a long period of food shortage before they were collected in August 1964.

Table 8.--Concentrations of DDT and DDE in water and fish from two test and two control streams during 1964 field season, Prince of Wales Island, Alaska

[Trace, < 0.005 p.p.m. in water, < 0.02 p.p.m. in fish]

Date and material	Test streams				Control streams			
	Cabin Creek		Virginia Lake		Old Tom Creek		Saltery Cove Creek	
	DDT	DDE	DDT	DDE	DDT	DDE	DDT	DDE
	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.
June 26:								
Water.....	Trace	--	Trace	--	Trace	--	Trace	--
Fish.....	0.14	1.1	1.40	2.40	do	Trace	do	Trace
July 18:								
Fish.....	.14	.65	.65	2.60	do	do	do	do
August 12:								
Fish.....	.17	.61	.49	1.30	do	do	--	--

Table 9.--Average condition factor (K) of trout from Cabin Creek and Virginia Lake (test waters) and Old Tom and Saltery Cove Creeks (control streams before spraying (1962) and after 1963-64)

[Number of specimens in parentheses. Fork length was used to calculate K]

Date	Test waters		Control streams	
	Cabin Creek (Rainbow trout)	Virginia Lake (Cutthroat trout)	Old Tom Creek (Rainbow trout)	Saltery Cove Creek (Rainbow trout)
1962:				
July.....	0.92 (25)	0.86 (18)	0.91 (93)	0.79 (26)
August.....	.93 (85)	.91 (49)	.92 (100)	.89 (16)
1963:				
July.....	.87 (100)	.84 (34)	.89 (100)	.84 (26)
August.....	.87 (75)	.88 (34)	.88 (75)	.89 (26)
1964:				
July.....	.83 (49)	.81 (42)	.89 (68)	.83 (33)
August.....	.82 (49)	.79 (16)	.90 (34)	.81 (9)

EVALUATION OF EFFECTS OF SPRAYING

Spraying had marked effects on aquatic insects and on fish in the streams but had no detectable effect on clams and plankton near the stream mouths.

Aquatic Insects

The most dramatic effect of the 1963 spraying was the immediate annihilation of aquatic insects in the test streams. In the control streams the abundance of insects followed the normal seasonal changes.

Sampling of drifting insects collected on June 21, after spraying, (table 4) contained more Ephemeroptera than Diptera--the reverse of the relation in the prespray samples from stones. This finding agrees with that of Hoffman and Surber (1949), who reported Ephemeroptera to be more susceptible to DDT than the chironomid Diptera. The unexpectedly high ratio of Ephemeroptera to Diptera in samples of drifting insects in my study may have been caused by the relative sizes and shapes of the two kinds of insects. The mayfly nymphs were larger than the Diptera larvae and had longer appendages. Many of the mayflies became tangled in the mesh, whereas many of the smaller Diptera may have passed through.

Repopulation of insects on the sample stones in streams of the sprayed watersheds was insignificant during the summer of 1963. The only invertebrate observed during the first month after spraying was the water mite. About 1 mo. (month) after spraying I found a few minute Ephemeroptera nymphs on stones in both test streams and a beetle larva in Virginia Creek. The first postspray observation of a stonefly in the test streams was on August 4 in Cabin Creek. Two stoneflies were found on September 11 in Virginia Creek.

Further evidence of the slow recovery of aquatic insects was shown by the stomach contents of rainbow trout from Cabin Creek in July and August (table 1). Only a few mayflies and aquatic Diptera were found in 1963, whereas in 1962 and 1964 the mayflies and aquatic Diptera were abundant.

On the basis of experiments reported in the literature, I expected the insect populations in the Skowl Arm streams to recover by the end of the summer of spraying, but they did not. By June 1964, however, the numbers of Diptera and Ephemeroptera on test stones in Cabin and Virginia Creeks approached the prespray levels. Repopulation may have resulted from eggs deposited before spraying, from eggs deposited after spraying by adult insects from untreated areas, or from a high survival of the progeny of a few individuals that survived the spray. Because the species of insects were not determined, life history information cannot help explain the rates of recovery.

Ide (1957) found that postspray abundance of chironomid Diptera exceeded the normal prespray levels, but this increase did not occur in the test streams in my investigation.

Fish

No deaths of fish from DDT were observed during this study, although adverse effects on fish of higher concentrations of DDT have been reported elsewhere. Brook trout (Salvelinus fontinalis) were killed after an application of DDT at the rate of 4.47 to 6.7 kg. per hectare in Ontario (Langford, 1949); several species of fish were killed by an application of 1.12 kg. per hectare in Idaho (Adams, Hanavan, Hosley, and Johnston, 1949);

and 0.56 kg. per hectare killed salmon, trout, and suckers in streams in New Brunswick (Kerswill and Elson, 1955). In my study, rainbow trout held in cages at the stream mouths were apparently unaffected by the application of DDT at the rate of 0.28 kg. per hectare, and no fish showed symptoms of DDT poisoning (erratic and uncoordinated swimming, tremors, and gulping of air at the surface--Rudd and Genelly, 1956) in Cabin Creek or the Virginia Creek system after the spraying. Trout from the stream and lake in the treated watersheds showed no evidence of blindness as reported by Alderdice and Worthington (1959) who held coho salmon in aquariums in DDT concentrations of 0.36 p.p.m. The effects of the high concentrations of DDT and DDE in tissues of cutthroat trout in Virginia Lake were not assessed. The mean condition factor of the fish from Virginia Lake continued to decline in 1964, but this decrease may have been a result of a decrease in the aquatic insects in the lake rather than the effects of DDT itself. No attempt was made to determine the abundance of aquatic insects in the lake. The lower condition factor of fish in Cabin Creek after spraying in 1963 was probably due to the lack of aquatic insects, which were scarce in the stream and in trout stomachs.

Clams and Plankton

Trace amounts of DDT and DDE were found in 14 of the 15 samples of clams. A prespray sample from the vicinity of Cabin Creek contained 0.03 p.p.m. DDE. The filter feeding and long life of clams should give them a great potential for accumulation of DDT and DDE. Only trace amounts of DDT were found in samples of plankton. Because we do not know how long the plankton remained in the vicinity of the creek, these data may not be meaningful. Measurement of effects on marine clams and plankton should be included, however, if a widescale insecticide program is begun in southeastern Alaska.

CONCLUSIONS

Although direct harmful effects on fishes from DDT sprayed at the relatively low rate of one-fourth pound per acre were not demonstrated in this study, the accompanying drastic reduction of aquatic insects could reduce growth and survival significantly. The effect of a reduction in aquatic insects would vary among different species of fish. Pink and chum salmon would be relatively unaffected by a program for control of the black-headed budworm with DDT because the optimum time for achieving maximum kill of the insect is in early summer. Pink and chum salmon fry migrate to sea in the spring, and the adult spawners enter the streams in midsummer and late summer. Furthermore, these two species do not feed extensively in fresh water. Sockeye salmon, coho salmon, and king salmon (O. tshawytscha) could be affected seriously, however, because a substantial portion of their lives is usually spent in streams and lakes where aquatic insects may be a significant part of their food (Synkova, 1951; Merrell, 1964).

The present study has shown that condition factors of trout resident in streams were reduced for at least 2 yr. after the watershed was sprayed with DDT. Control of forest insects with aerial application of DDT in watersheds containing lakes and streams thus may have adverse effects on coho, sockeye, and king salmon and on trout.

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